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The Effect of Season of Picloram and Chlorsulfuron Application on Dalmatian Toadflax (*Linaria genistifolia*) on Prescribed Burns[1]

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Abstract: Herbicides are an important tool for managing weeds where prescribed fire is used for rangeland improvement. Understanding how the season of herbicide application relates to prescribed burning is important. Our objective was to determine the effect of picloram and chlorsulfuron on Dalmatian toadflax cover, density, and biomass, where these herbicides were applied in the fall before burning or in the spring before or after burning. Six herbicide treatments and an untreated check were applied in a randomized complete block design with four replications to a prescribed burn at two sites infested with Dalmatian toadflax in Montana, United States. Herbicides were applied in the fall preburn, spring preburn, and spring postburn. Site 1 was treated in 1999 and 2000, and site 2 was treated in 2000 and 2001. Cover, biomass, and density of Dalmatian toadflax were sampled in September 2000, 2001, and 2002 at site 1 and September 2001 and 2002 at site 2. At site 1, cover, biomass, and density of Dalmatian toadflax were at least 76% lower compared with the check in both spring-applied picloram treatments, whereas the fall picloram treatment had similar Dalmatian toadflax cover, biomass, and density compared with the check 3 yr after application. By 2002, chlorsulfuron reduced Dalmatian toadflax cover, biomass, and density by at least 79% compared with the check in all timings of application at site 1. At site 2, Dalmatian toadflax cover, biomass, and density were reduced by at least 86% for all picloram and chlorsulfuron treatments in 2002, 2 yr after application. Chlorsulfuron applied in the fall or the spring and picloram applied in the spring effectively suppressed Dalmatian toadflax cover, biomass, and density for up to 3 yr.

Nomenclature: Chlorsulfuron; picloram; Dalmatian toadflax, *Linaria genistifolia* ssp. *dalmatica* (L.) Maire #[3] LINDA.

Additional index words: Integrated weed management, invasive weeds, noxious rangeland weeds, restoration using fire and herbicides.

INTRODUCTION

Prescribed fire has been used to restore rangelands by reducing nonsprouting shrubs and trees, releasing nutrients bound in plant material, and removing heavy litter that can hinder understory plant growth. However, many invasive plants may also respond positively to postfire conditions (Jacobs and Sheley 2003a). In the Rocky Mountains and throughout much of the western United States, Dalmatian toadflax, a perennial invasive weed native to the Mediterranean region (Lajeunesse 1999), threatens to dominate plant communities after many prescribed burns. Jacobs and Sheley (2003a) found that Dalmatian toadflax increased biomass and seed production 2- to 10-fold in areas burned during the spring to restore native plant communities compared with adjacent areas that did not burn.

The response of Dalmatian toadflax to herbicidal control is variable. Picloram applied at 0.5, 1.1, or 2.25 kg ae/ha effectively controlled Dalmatian toadflax at various growth stages for 1 yr (Ferrell and Whitson 1987; Robocker et al. 1972), but these high picloram rates may have adverse effects on nontarget desirable plant species that may compete with toadflax (Denny 2003). Duncan et al. (1999) applied picloram at 0.28, 0.38, and 0.56 kg/ha on Dalmatian toadflax in Utah and Montana at flowering and fall regrowth. In Utah, applications at flowering provided significantly greater control (>80%) than applications at fall regrowth (<80%) 1 yr after treatment. In Montana, picloram provided greater than 90% control when applied at flowering and greater than 80% when applied at fall regrowth 1 yr after treatment. Re-

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

peated annual treatments increased control in that study (Duncan et al. 1999). Triclopyr, fluroxypyr, and triclopyr combined with 2,4-D or fluroxypyr were ineffective in controlling Dalmatian toadflax (Ferrell and Whitson 1987). There is little published information on using chlorsulfuron to control Dalmatian toadflax. However, Bussan et al. (2001) recommended chlorsulfuron application at 0.11 kg ai/ha to actively growing toadflax in the spring or fall.

Timing of herbicide application relative to prescribed fire may affect weed control. Wolters et al. (1994) used picloram plus 2,4-D in combination with prescribed grassland fire to manage leafy spurge in North Dakota. They found fall picloram application followed by a spring burn was the most effective treatment for reducing leafy spurge seed germination and stem density. Many herbicides, such as chlorsulfuron, are most effective during spring when the plants are actively growing. Several other factors may also influence the effectiveness of herbicides applied pre- and postburn. For example, chlorsulfuron or picloram applied before burning may be intercepted by shrub, tree, or litter cover and prevent adequate coverage on weeds or soil (or both). Reducing litter cover by burning can alter water infiltration (Beutner and Anderson 1943), increase erosion (Boyer and Dell 1980), and increase solar radiation, which could affect chlorsulfuron and picloram residual activity. In addition, soil bacterial populations increase 3- to 10-fold within a month after fire (Miller et al. 1955), and fire can destroy up to 95% of picloram residue,[4] thereby reducing the longevity of control.

Combining herbicidal control of weeds with prescribed fires to restore rangeland where weeds or weed seeds are present may minimize weed establishment and dominance after burning; however, there is little information on the effectiveness of herbicides applied in relation to the timing of prescribed fire. The objective of this study was to determine the effect of picloram and chlorsulfuron on Dalmatian toadflax cover, density, and biomass when applied in the fall before a spring-prescribed burn or in the spring before or after a prescribed burn. We hypothesized that picloram and chlorsulfuron would reduce Dalmatian toadflax cover, biomass, and density most when applied in the spring, and postburn application of either herbicide would provide more effective toadflax control than preburn herbicide application.

[4] USDA Forest Service: http://infoventures.com/e-hlth/pesticide/picloram.html.

MATERIALS AND METHODS

The study was conducted in 2000, 2001, and 2002 on two sites in the Elkhorn Mountains of southwestern Montana, United States (site 1: 46°19′24″N 11°47′42″W, elevation 1,875 m and site 2: 49°19′48″N 136°48′04″W, elevation 1,600 m). Both sites were within big sagebrush–bluebunch wheatgrass [*Artemesia tridentata* Nutt.–*Pseudorogneria spicata* (Pursh) Löve] habitat types (Mueggler and Stewart 1980). Site 1 soil was Maiden-Lap-rock outcrop complex consisting of loamy-skeletal, carbonic Typic Calciborolls, and site 2 soil was Windham-Lap very cobbly loams consisting of loamy-skeletal, carbonic Typic Calciborolls. The average slope was 20 and 5% at site 1 and site 2, respectively. Average annual precipitation at both sites was 297 mm with 56% falling May through August. Soil pH ranged from 7.5 to 8.3 with a mean of 7.8, and organic matter ranged from 2.0 to 3.3% with a mean of 2.9%. The predominant vegetation was big sagebrush with bluebunch wheatgrass, green needlegrass (*Stipa viridula* Trin.), and elk sedge (*Carex geyeri* Boott.) in the understory. Ground covered by dead plant litter was 38% and uniform before burning and 7% and patchy after burning. Dalmatian toadflax was evenly distributed at both sites with densities of 62.5 (SD = 14.2) and 25.4 (SD = 7.7) stems/m^2 before burning at site 1 and site 2, respectively.

The herbicide treatments were picloram or chlorsulfuron applied in the fall the year before spring-prescribed burns, or in the spring approximately 2 wk before burning, or in the spring approximately 2 wk after burning, and a check where no herbicide was applied. The seven treatments were randomized by block within four replications at each site. All plots including the check were burned. Picloram was applied at 0.56 kg ae/ha and chlorsulfuron was applied at 0.075 kg ai/ha, using a four-nozzle backpack plot sprayer delivering 40 L/ha. A nonionic surfactant was added to the herbicide solutions at 0.5% by volume. Plots were 6 by 4 m. The dates of application at site 1 were October 20, 1999; March 29, 2000; and April 27, 2000; and those at site 2 were November 2, 2000; March 26, 2001; and May 9, 2001. Dalmatian toadflax was in the rosette growth stage at all timings of herbicide application at both sites. Site 1 was burned on April 11, 2000, and site 2 was burned on April 25, 2001. The fires burned uniformly at both sites at an average rate of 250 m/h, consumed nearly all the plant litter, and killed most of the trees and shrubs.

Treatment effects on Dalmatian toadflax cover, density, and biomass were measured in September 2000, 2001, and 2002 at site 1 and in September 2001 and

Table 1. P values generated from ANOVA for herbicide treatment, year, and treatment by year effects on Dalmatian toadflax cover, density, and biomass at two sites in southwestern Montana.

		Cover		Density		Biomass	
Source	df	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Replication	3	0.0656	0.9226	0.1914	0.7955	0.0197	0.8523
Year	2	0.0001	0.3008	0.0268	0.2394	0.0002	0.0409
Treatment	6	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Year by treatment	12	0.0033	0.6254	0.0735	0.0067	0.0339	0.9104

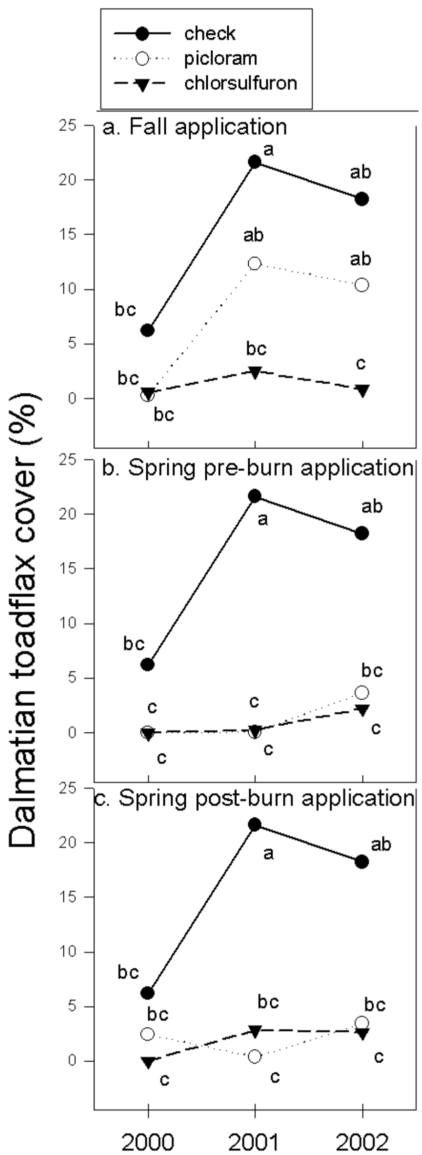

Figure 1. The interaction effect of herbicide treatment and year on Dalmatian toadflax percent cover. Observed means are presented for data from site 1 in 2000, 2001, and 2002 where picloram and chlorsulfuron were applied on a prescribed burn in the fall preburn, spring preburn, and spring postburn. The control data are the same in each graph. Letters following means indicate differences determined by Bonferroni *t* tests at $\alpha = 0.05$ and can be used to compare means within graphs and between graphs.

2002 at site 2. One 0.44-m^2 hoop was placed at random on the ground within each plot, and the Dalmatian toadflax percent of total ground cover was estimated. The number of Dalmatian toadflax rosettes and flowering stems were counted within the hoop and then clipped at the soil surface. Clipped stems and rosettes were dried at 60 C for 48 h and weighed. A different area within each plot was sampled each year.

ANOVA was used to determine treatment and year effects on Dalmatian toadflax cover, density, and biomass.[5] Sites were analyzed separately because the experiment was initiated at different times. The model used for each site included replication, year, treatment, and the year by treatment interaction. Data were square root transformed to meet assumptions of normality and homogeneity of variance. For ease of interpretation, the observed means are presented. When P values were less than 0.1, Bonferroni *t* tests ($\alpha = 0.05$) were used for mean separations (Miller 1981).

RESULTS AND DISCUSSION

Site 1. Treatment and year interacted to affect Dalmatian toadflax cover at site 1 (Table 1). In 2000, Dalmatian toadflax cover was less than 10% in all treatments including the check, and there were no differences among treatments (Figure 1). In 2001, Dalmatian toadflax cover increased to 20% in the check, which was greater than all the spring-applied treatments and the fall chlorsulfuron treatment but not the fall picloram treatment. By 2002, Dalmatian toadflax cover was lower in all chlorsulfuron treatments than the check and the fall picloram treatment. Cover in spring-applied picloram treatments was lower than the check, and fall-applied picloram was no different than the check.

Treatment and year interacted to affect Dalmatian toadflax biomass at site 1 (Table 1). The response of biomass to treatments in each year was similar to the response of cover to treatments (Figure 2). Biomass production of Dalmatian toadflax was 20 g/m^2 or less in all

[5] SAS Inc. 1990, SAS Campus Drive, Cary, NC 27513.

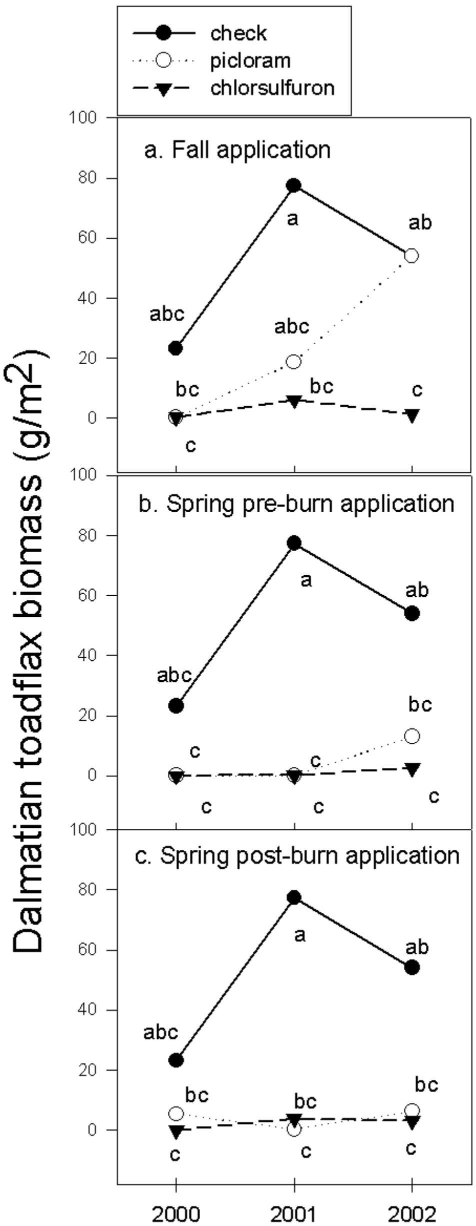

Figure 2. The interaction effect of herbicide treatment and year on Dalmatian toadflax biomass. Observed means are presented for data from site 1 in 2000, 2001, and 2002 where picloram and chlorsulfuron were applied on a prescribed burn in the fall preburn, spring preburn, and spring postburn. The control data are the same in each graph. Letters following means indicate differences determined by Bonferroni *t* tests at $\alpha = 0.05$ and can be used to compare means within graphs and between graphs.

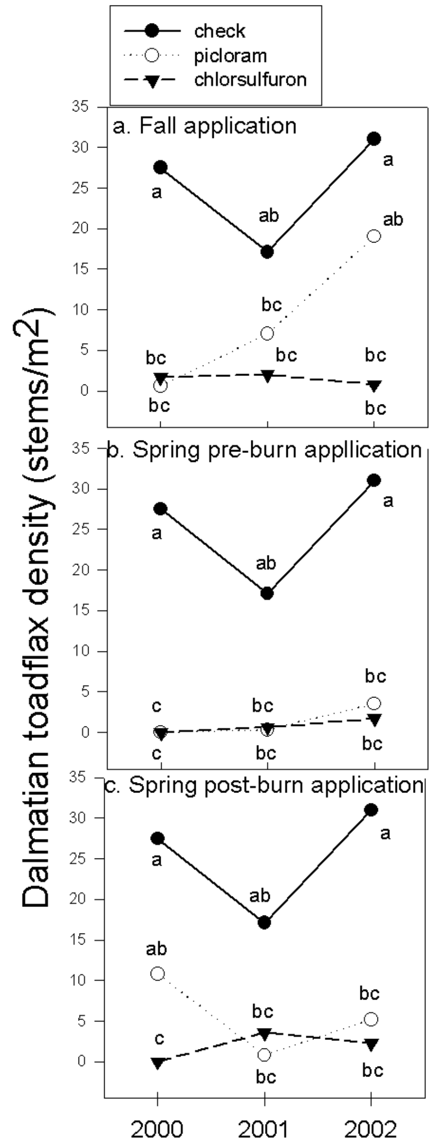

Figure 3. The interaction effect of herbicide treatment and year on Dalmatian toadflax density. Observed means are presented for data from site 1 in 2000, 2001, and 2002 where picloram and chlorsulfuron were applied on a prescribed burn in the fall preburn, spring preburn, and spring postburn. The control data are the same in each graph. Letters following means indicate differences determined by Bonferroni *t* tests at $\alpha = 0.05$ and can be used to compare means within graphs and between graphs.

treatments in 2000. It nearly quadrupled to 75 g/m^2 in 2001 in the check. Biomass in the fall picloram treatment was no different than the check in 2001 despite it being less than 20 g/m^2. All other treatments resulted in lower biomass production compared with the check in that year. By 2002, no picloram treatments resulted in significantly less biomass than the check, and Dalmatian toadflax biomass was the same in the fall picloram treatment as the check. All chlorsulfuron treatments yielded lower biomass than the check but not the spring picloram treatments.

Treatment and year interacted to affect Dalmatian toadflax density at site 1 (Table 1). All treatments except the spring postburn picloram treatment reduced Dalmatian toadflax density in 2000 (Figure 3). In 2001, herbicide treatment results were not different than the check. All treatments except the fall picloram resulted in less density compared with the check but were not different than the fall picloram treatment in 2002.

Table 2. Mean values from observed data for Dalmatian toadflax cover at site 1 and biomass at site 2. Letters following means indicate differences determined by Bonferroni *t* tests at $\alpha = 0.05$.

Treatment	Cover	Biomass
	%	g/m²
Control	16.6 a	81.9 a
Fall picloram	1.1 b	3.1 b
Fall chlorsulfuron	0.6 b	0.4 b
Spring preburn picloram	1.0 b	0.4 b
Spring preburn chlorsulfuron	0.3 b	0.2 b
Spring postburn picloram	0.6 b	0.1 b
Spring postburn chlorsulfuron	0.2 b	0.1 b

Site 2. Treatment affected Dalmatian toadflax cover and biomass at site 2 (Table 1). All treatments reduced cover and biomass compared with the check, and there were no differences between treatments (Table 2). Year affected Dalmatian toadflax biomass at site 2 (Table 1). Averaged across all treatments, Dalmatian toadflax biomass was 5.7 g/m² in 2001 compared with 2.4 g/m² ($P < 0.05$) in 2002.

Treatment and year interacted to affect Dalmatian toadflax density at site 2 (Table 1). Treatment did not affect density in 2001. In 2002, all treatments reduced density compared with the check, and there were no differences among treatments (Figure 4).

Managers are concerned about the effects of prescribed fires on Dalmatian toadflax spread. Jacobs and Sheley (2003a) found Dalmatian toadflax increased biomass and seed production 2- to 10-fold in spring-prescribed burns compared with areas that did not burn. In this study, biomass production of Dalmatian toadflax was 20 g/m² or less in all treatments in 2000 at site 1. It nearly quadrupled to 75 g/m² in 2001 in the check although 2001 biomass was not significantly different than 2000 biomass at site 1. Cover did significantly increase from 2000 to 2001. Although there was no nonburned check for comparison, these data provide additional evidence that Dalmatian toadflax increases after fire and argue in favor of aggressive control of this weed after fire.

We found picloram more effective in controlling Dalmatian toadflax when applied in the spring compared with the fall. Our results from site 1 are consistent with those reported by Duncan et al. (1999), who found timing of application affected Dalmatian toadflax response to picloram. In that study, picloram applied at the flower stage provided more consistent control of Dalmatian toadflax than picloram applied in the fall. Dalmatian toadflax was in the rosette stage in our fall and spring treatments. Cover, density, and biomass were not different in the fall picloram treatment compared with the

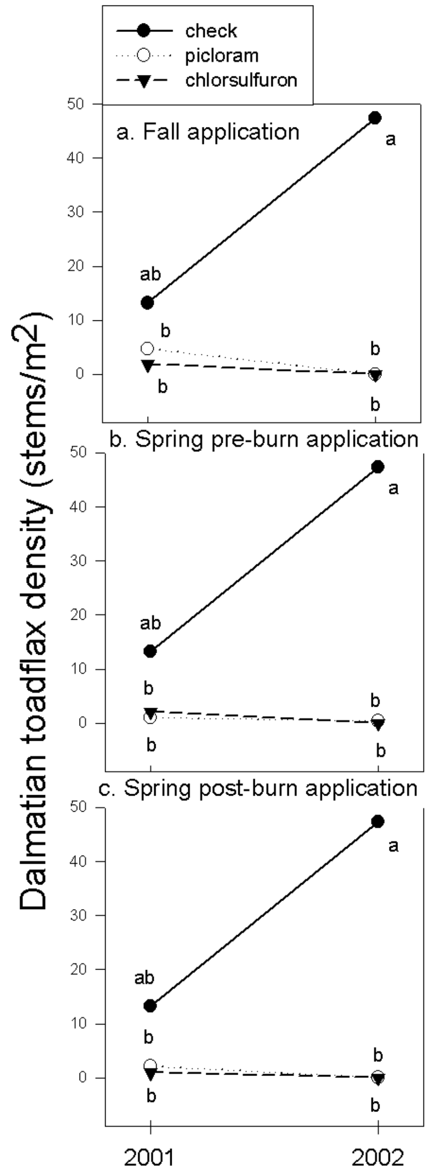

Figure 4. The interaction effect of herbicide treatment and year on Dalmatian toadflax percent cover. Observed means are presented for data from site 2 in 2001 and 2002 where picloram and chlorsulfuron were applied on a prescribed burn in the fall preburn, spring preburn, and spring postburn. The control data are the same in each graph. Letters following means indicate differences determined by Bonferroni *t* tests at $\alpha=0.05$ and can be used to compare means within graphs and between graphs.

check in any of the years, whereas both spring applications of picloram reduced cover and biomass in 2001 at site 1. These results support our hypothesis that a spring herbicide application is more effective in reducing Dalmatian toadflax cover and biomass than a fall application. However, there were no differences in Dalmatian toadflax control when chlorsulfuron was applied in the fall compared with the spring application. In addition, there were no differences between fall and spring applications of either herbicide at site 2 in the second year after application.

The responses of Dalmatian toadflax cover, biomass, and density to the spring preburn compared with the spring postburn applications were the same, in most cases. This finding suggests that there was little combustion of the herbicide residual when the herbicide was applied before the fire or that enough of the herbicide made it into the plants or soil so that fire did not affect it. We can also speculate that burning the litter did not affect herbicide residual because of increased solar radiation, water infiltration, or runoff (Beutner and Anderson 1943). It also indicates that there was no increase in residual breakdown by increased microbial activity (Miller et al. 1955). The only difference we found between spring pre- and postburn applications was density in 2000 at site 1 where picloram was applied. In this case, the postburn application was not different than the control, but the preburn application was less than the control. However, there were no differences in Dalmatian toadflax density response between the spring pre- and postburn applications in 2001 and 2002 at this site. We hypothesized that the postburn picloram and chlorsulfuron applications would more effectively reduce Dalmatian toadflax cover, biomass, and density than the preburn applications. Our results support rejecting the hypothesis. This suggests that there may be no advantage to applying picloram or chlorsulfuron in the spring after, rather than before, a spring-prescribed burn.

Herbicidal management of Dalmatian toadflax on prescribed burns is important for preventing weed population explosions after burning. Dalmatian toadflax has the potential to increase biomass and seed production after fire (Jacobs and Sheley 2003a). Chlorsulfuron applied in the fall or the spring pre- or postburn and picloram applied in the spring pre- or postburn effectively suppressed Dalmatian toadflax cover, biomass, and density for up to 3 yr at site 1 and 2 years at site 2 and left safe sites and nutrients released by fire available to desirable plant species (Jacobs and Sheley 2003b).

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